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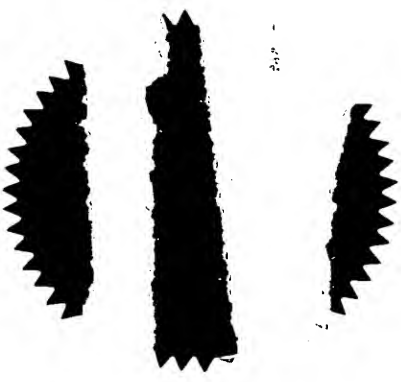
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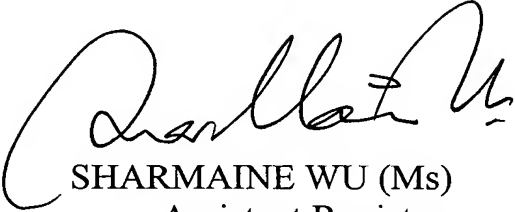
Date of Filing : 02 SEPTEMBER 2002

Application Number : 200205347-8

Applicant(s) /
Proprietor(s) of Patent : OKI TECHNO CENTRE (SINGAPORE) PTE
LTD

Title of Invention : A RECEIVER AND A SIGNAL PROCESSING
CIRCUIT THEREFORE




SHARMAINE WU (Ms)
Assistant Registrar
for REGISTRAR OF PATENTS



ACTION

PATENTS FORM 1

Patents Act
(Cap. 221)
Patents Rules
Rule 19

INTELLECTUAL PROPERTY OFFICE OF SINGAPORE

**REQUEST FOR THE GRANT OF A PATENT UNDER
SECTION 25**



101101

* denotes mandatory fields

1. YOUR REFERENCE*

SP5226

**2. TITLE OF
INVENTION***

A RECEIVER AND A SIGNAL PROCESSING CIRCUIT THEREFOR

3. DETAILS OF APPLICANT(S)* (see note 3)

Number of applicant(s)

1

(A) Name

Oki Techno Centre (Singapore) Pte Ltd

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State

Country

SG

☒

For corporate applicant

☐

For individual applicant

State of incorporation

State of residency

Country of incorporation

SG

Country of residency

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For others (please specify in the box provided below)

(B) Name

Address

State

Country



☐

For corporate applicant

☐

For individual applicant

State of incorporation

State of residency

Country of incorporation

Country of residency

☐

For others (please specify in the box provided below)

(C) Name

Address

State

Country

☐

For corporate applicant

☐

For individual applicant

State of incorporation

State of residency

Country of incorporation

Country of residency

☐

For others (please specify in the box provided below)

☐

Further applicants are to be indicated on continuation sheet 1

4. DECLARATION OF PRIORITY (see note 5)

A. Country/country designated

DD MM YYYY

File number

Filing Date

B. Country/country designated

DD MM YYYY

File number

Filing Date

☐

Further details are to be indicated on continuation sheet 6

5. INVENTOR(S)* (see note 6)

A. The applicant(s) is/are the sole/joint inventor(s)

Yes

☐

No

☒02 SEP 2002
200205347-8

B. A statement on Patents Form 8 is/will be furnished

Yes

☒

No

☐

6. CLAIMING AN EARLIER FILING DATE UNDER (see note 7)

☐

section 20(3)

☐

section 26(6)

☐

section 47(4)

Patent application number

DD MM YYYY

Filing Date

Please mark with a cross in the relevant checkbox provided below
(Note: Only one checkbox may be crossed.)

☐

Proceedings under rule 27(1)(a)

DD MM YYYY

Date on which the earlier application was amended

☐

Proceedings under rule 27(1)(b)

7. SECTION 14(4)(C) REQUIREMENTS (see note 8)

Invention has been displayed at an international exhibition. Yes

☐

No

☒

8. SECTION 114 REQUIREMENTS (see note 9)

The invention relates to and/or used a micro-organism deposited for the purposes of disclosure in accordance with section 114 with a depository authority under the Budapest Treaty.

Yes

☐

No

☒

9. CHECKLIST*

(A) The application consists of the following number of sheets

i. Request

5

Sheets

ii. Description

12

Sheets

iii. Claim(s)

2

Sheets

iv. Drawing(s)

5

Sheets

v. Abstract
(Note: The figure of the drawing, if any, should accompany the abstract)

1

Sheets

Total number of sheets

25

Sheets

(B) The application as filed is accompanied by:

☐

Priority document(s)

☐

Translation of priority document(s)

☒

Statement of inventorship
& right to grant

☐

International exhibition certificate

10. DETAILS OF AGENT (see notes 10, 11 and 12)

Name

Firm

LLOYD WISE

11. ADDRESS FOR SERVICE IN SINGAPORE* (see note 10)

Block/Hse No.

Level No.

Unit No./PO Box

Street Name

P.O BOX 636

Building Name

TANJONG PAGAR POST OFFICE

Postal Code

910816

12. NAME, SIGNATURE AND DECLARATION (WHERE APPROPRIATE) OF APPLICANT OR AGENT* (see note 12)

(Note: Please cross the box below where appropriate.)

☒

I, the undersigned, do hereby declare that I have been duly authorised to act as representative, for the purposes of this application, on behalf of the applicant(s) named in paragraph 3 herein.

Name and Signature

LLOYD WISE

DD MM YYYY

02 09 2002

Our Ref: SP5226

NOTES:

1. This form when completed, should be brought or sent to the Registry of Patents together with the rest of the application. Please note that the filing fee should be furnished within the period prescribed.
2. The relevant checkboxes as indicated in bold should be marked with a cross where applicable.
3. Enter the name and address of each applicant in the spaces provided in paragraph 3.
Where the applicant is an individual
 - Names of individuals should be indicated in full and the surname or family name should be underlined.
 - The address of each individual should also be furnished in the space provided.
 - The checkbox for "For individual applicant" should be marked with a cross.
Where the applicant is a body corporate
 - Bodies corporate should be designated by their corporate name and country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided.
 - The address of the body corporate should also be furnished in the space provided.
 - The checkbox for "For corporate applicant" should be marked with a cross.
Where the applicant is a partnership
 - The details of all partners must be provided. The name of each partner should be indicated in full and the surname or family name should be underlined.
 - The address of each partner should also be furnished in the space provided.
 - The checkbox for "For others" should be marked with a cross and the name and address of the partnership should be indicated in the box provided.
4. In the field for "Country", please refer to the standard list of country codes made available by the Registry of Patents and enter the country code corresponding to the country in question.
5. The declaration of priority in paragraph 4 should state the date of the previous filing, the country in which it was made, and indicate the file number, if available. Where the application relied upon in an International Application or a regional patent application e.g. European patent application, one of the countries designated in that application [being one falling under section 17 of the Patents Act] should be identified and the country should be entered in the space provided.
6. Where the applicant or applicants is/are the sole inventor or the joint inventors, paragraph 5 should be completed by marking with a cross the 'YES' checkbox in the declaration (A) and the 'NO' checkbox in the alternative statement (B). Where this is not the case, the 'NO' checkbox in declaration (A) should be marked with a cross and a statement will be required to be filed on Patents Form 8.
7. When an application is made by virtue of section 20(3), 26(6) or 47(4), the appropriate section should be identified in paragraph 6 and the number of the earlier application or any patent granted thereon identified. Applicants proceeding under section 26(6) should identify which provision in rule 27 they are proceeding under. If the applicants are proceeding under rule 27(1)(a), they should also indicate the date on which the earlier application was amended.
8. Where the applicant wishes an earlier disclosure of the invention by him at an International Exhibition to be disregarded in accordance with section 14(4)(c), then the 'YES' checkbox at paragraph 7 should be marked with a cross. Otherwise, the 'NO' checkbox should be marked with a cross.
9. Where in disclosing the invention the application refers to one or more micro-organisms deposited with a depository authority under the Budapest Treaty, then the 'YES' checkbox at paragraph 8 should be marked with a cross. Otherwise, the 'NO' checkbox should be marked with a cross. Attention is also drawn to the Fourth Schedule of the Patents Rules.
10. Where an agent is appointed, the fields for "DETAILS OF AGENT" and "ADDRESS FOR SERVICE IN SINGAPORE" should be completed and they should be the same as those found in the corresponding Patents Form 41. In the event where no agent is appointed, the field for "ADDRESS FOR SERVICE IN SINGAPORE" should be completed, leaving the field for "DETAILS OF AGENT" blank.
11. In the event where an individual is appointed as an agent, the sub-field "Name" under "DETAILS OF AGENT" must be completed by entering the full name of the individual. The sub-field "Firm" may be left blank. In the event where a partnership/body corporate is appointed as an agent, the sub-field "Firm" under "DETAILS OF AGENT" must be completed by entering the name of the partnership/body corporate. The sub-field "Name" may be left blank.
12. Attention is drawn to sections 104 and 105 of the Patents Act, rules 90 and 105 of the Patents Rules, and the Patents (Patent Agents) Rules 2001.
13. Applicants resident in Singapore are reminded that if the Registry of Patents considers that an application contains information the publication of which might be prejudicial to the defence of Singapore or the safety of the public, it may prohibit or restrict its publication or communication. Any person resident in Singapore and wishing to apply for patent protection in other countries must first obtain permission from the Singapore Registry of Patents unless they have already applied for a patent for the same invention in Singapore. In the latter case, no application should be made overseas until at least 2 months after the application has been filed in Singapore, and unless no directions had been issued under section 33 by the Registrar or such directions have been revoked. Attention is drawn to sections 33 and 34 of the Patents Act.
14. If the space provided in the patents form is not enough, the additional information should be entered in the relevant continuation sheet. Please note that the continuation sheets need not be filed with the Registry of Patents if they are not used.

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A RECEIVER AND A SIGNAL PROCESSING CIRCUIT THEREFOR

Field of the Invention

5 The present invention relates to a receiver suitable for a frequency modulated signal more particularly, but not exclusively applicable for use with the Bluetooth protocol.

Description of the Prior Art

10

In most wireless transceiver integrated circuits, linearity, power consumption and production yield are the most important challenges to system and circuit design engineers. Conventional ways to overcome the linearity problem are to increase power and use AGC to slide the dynamic range. However, power is
15 precious in today's portable electronic applications and feedback AGC architecture is too slow to respond in some applications, such as Bluetooth, which has only 4 preambles. In the Bluetooth protocol, a particular problem is the design of the dataslicer. Due to the burst mode nature, short preambles and system frequency offset of Bluetooth, the design problem of an analog data
20 slicer becomes formidable and yield becomes a major issue. One way to overcome this is to use an advanced digital signal processing method.

A semiconductor integrated circuit which aims to overcome the problems of linearity, power and consistency has been proposed by Conexant Systems Inc.

[2001 IEEE International Solid-State Circuits Conference / Session 13 /

Wireless LAN / 13.4] . In this paper, a low IF receiver architecture is used. The

5 RF is converted to 1 MHz IF and passed through a number of complex filter stages. Feed forward AGC with fine resolution (1~2 dB) is used at most of the stages. The IQ outputs from the IF filter is fed to two 6 bits ADCs which operate at 10 MHz. Finally the demodulator and dataslicer are implemented in the digital domain.

10

By using AGC, smaller power consumption can be achieved with the feed forward structure ensuring unconditionally stability. As the final demodulation and dataslicer are implemented digitally, consistency and hence production yield can be improved with careful design of the implementation algorithm.

15

The receiver structure disclosed by Conexant is an improvement on prior designs. However, the structure has some redundancy and also introduces extra challenges for the circuit design engineer since the feed forward AGC with high speed response and fine resolution required in the Conexant structure is
20 difficult to design and will have an impact on the steady state system bit error rate BER.

Summary of the Invention

According to the invention there is provided a signal processing circuit for a frequency modulated signal receiver comprising a complex filter connected to
5 analog to digital conversion means, the filter comprising first and second complex filter stages and a voltage limiter disposed between the stages.

Preferably the first filter stage is arranged to provide gain to a received signal and may comprise at least three complex poles.
10

Preferably the second filter stage is arranged to filter out higher order harmonics of a received signal and may comprise at least two complex poles.

Preferably, amplifier means disposed between the second filter stage and the
15 analog to digital conversion means and the amplifier means may comprise an automatic gain control amplifier having a signal level sensor and a controllable amplifier, with the sensor being preferably arranged to control the gain of the amplifier between two gain levels in dependence upon the level of a received signal, most preferably with the level sensor having hysteresis.

20

The analog to digital conversion means preferably comprises only a single analog to digital converter.

The output from the second filter stage may comprise two signals in phase quadrature, only one of which is input to the analog to digital converter means.

The circuit elements from the limiter to the analog to digital conversion means
5 are preferably arranged to limit the signal voltage to less than the maximum allowable range of the analog to digital conversion means.

The circuit may further comprise a mixer, connected to the first filter stage, preferably via DC decoupling means.

10

The described embodiment has particular application in the Bluetooth standard, in which the image rejection requirement is relatively relaxed and is achievable by a five stage complex filter. No further rejection is required in the digital domain and thus the IQ phase information is no longer needed, so analog to
15 digital conversion of either the I or Q signal is sufficient for subsequent digital processing.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

5

Figure 1 is a block diagram of a receiver including a processing circuit of a first embodiment of the invention;

Figure 2 shows the structure of a complex pole of the embodiment of Figure 1;

10

Figure 3 illustrates the response of each complex pole;

Figure 4 illustrates the combined response of all the complex poles; and

15 Figure 5 illustrates a second embodiment of the invention.

Detailed Description of the Preferred Embodiments

Figure 1 is a simplified circuit diagram showing a receiving architecture

20 according to the first embodiment of the present invention. The receiver is specifically for use with Bluetooth but is equally applicable for other frequency modulated signal applications.

An aerial 100 is connected to a LNA (low noise amplifier) 101 with a differential output, which is in turn electrically connected to a quadrature IQ mixer 102 which provides intermediate frequency (IF) I and Q outputs which are connected to a differential five pole complex filter 105, 106, 107, 108, 109, 110, 111 through coupling capacitors 103. The complex filter consists of five complex poles 105-107, 109, 110, a voltage limiter 108 and an amplifier 111. Gain is assigned to the first three poles 105-107, the output from the first three poles being electrically connected to the voltage limiter 108. The limiter is implemented using a hard clip topology, although soft clip can be used also.

The limiter 108 is electrically connected to another two complex poles 109, 110 which have insertion loss at the centre of the IF frequency. From pole 110, only the I or Q signal is electrically connected to the voltage amplifier 111. The output from the voltage amplifier 111 is electrically connected to an analog to digital convertor (ADC) 112. Finally, the ADC output is electrically connected to digital signal processing circuitry including a digital demodulator and dataslicer 115. Elements 101-112 form a single semiconductor integrated circuit receiving the signal input from aerial 100 and provided a digital signal output to digital signal processing circuitry 115, which may preferably also be built on the same IC.

20

The structure of a complex pole is shown in Figure 2. The pole receives I and Q input signals I_{in} and Q_{in} and provides output signals I_{out} and Q_{out} . I_{in}

is fed to a difference element where it is combined with Q_{out} received via an amplifier having gain $2Q$, where Q is the quality factor of the complex filter pole. Q_{in} is fed to a summing element where it is combined with I_{out} received via a further amplifier having gain $2Q$. A transfer function $1/(1+S/W_0)$ is applied to the

5 outputs from the sum and difference elements to form the outputs I_{out} and Q_{out} . The structure of all the complex poles is the same, with the frequency response of each pole being selected by choosing Q and W_0 accordingly. As shown in Figure 3, poles 1-3 have a relatively flat frequency response with poles 4 and 5 having much more pronounced peaks around the intermediate frequency. The

10 combined response of all the poles is shown in Figure 4.

The operation of the receiver in Fig. 1 will next be described. A single ended RF signal from antenna 100 or a BPF outside the semiconductor integrated circuit is input to LNA 101 and is amplified and converted to a differential RF signal.

15 The differential RF signal is then input to the mixer 102. 1 MHz differential quadrature Intermediate Frequency (IF) I and Q signals are obtained at the output of mixer 102 and are fed to the complex filter through coupling capacitors 103. The coupling capacitors 103 cut off all the DC level in the signals at interconnect 104. The AC signals at interconnect 104 are then

20 filtered and at the same time amplified by the first pole 105 of the complex filter. The output signals of the first pole 105 complex filter are DC connected to the next pole 106. The filtered and again amplified signals are DC connected to the next pole 107. The filtered and again amplified signals from pole 107 are then

electrically connected to a voltage limiter 108. The voltage limiter ensures that the AC voltage swing of the signals is smaller or equal to a pre-designed value X. The limited outputs are then input to another two complex poles 109 and 110 with insertion loss L1 and L2 respectively. Finally, the outputs from
 5 complex pole 110 are amplified by a voltage amplifier 111 with gain G. Only one of the IQ signals from amplifier 111 are sampled by a Nyquist rate ADC 112. The ADC has a maximum input range of Y volts. The limiter range, gain/insertion loss of complex poles 109, 110 and the input range of the ADC have the following relation :

10

$$Y \geq X * L1 * L2 * G$$

Typical values are X=0.5, L1=0.5, L2=0.63, G=4, Y=1

The digitized signal is then processed by the digital demodulator and dataslicer

15

115.

In the first embodiment as described above, the single ended RF signal from outside the semiconductor integrated circuit is converted by the LNA to differential signal without the use of a discrete BALUN which reduces the total
 20 number of discrete components. As the complex filter has finite attenuation at DC frequency, the coupling capacitors 103 help to reduce the second order effect of the LNA and mixer and also allows independent design of the common mode voltage for both mixer and complex filter. The built in gain in complex

poles 105, 106 and 107 helps to improve the signal to noise ratio of the desired signal. The limiter together with the complex poles 109, 110 and amplifier 111 will ensure that the largest signal at the ADC 112 input is smaller than the ADC maximum input range. As the desired signal is frequency modulated, non-

5 linearity at the limiter has no severe impact on the signal integrity. To allow a low sampling rate analog-digital converter (of 4 MHz sampling rate for a signal of $IF=1$ MHz and bandwidth 1MHz) to be used, another two poles are added after the limiter to filter away the third and higher harmonics produced at the limiter 108 output which would otherwise be folded back to the signal band.

10

For a small received signal, this will experience a complete complex filter response, however for a large signal, the signal will effectively experience a limiter following by two complex poles. Hence, in principle there is no upper limit to the usable input range. The Bluetooth specification requires a receiver

15 circuit with minimum 90 dB dynamic range. However, with architecture as describe above, a 45~48 dB dynamic range ADC will be able to meet and exceed this requirement.

20

Figure 2 shows a second embodiment of the invention being a slight modification of the embodiment of Figure 1. The main difference is the addition of a simple one step hysteresis AGC amplifier 113, 114. This AGC is placed after the complex filter chain to replace the original simple amplifier 111.

The AGC consists of two parts: namely hysteresis signal sensor 114 and a controllable two step voltage gain amplifier 113. The differential output of the complex filter chain is electrically connected to both signal sensor and two step gain control amplifier. The output of the sensor 114 is electrically connected to the control pin of the amplifier 113. The output of the amplifier is then electrically connected to the ADC 112 for further digital processing.

The operation of the second embodiment before the AGC 113,114 is exactly the same as the first embodiment. When the input signal to AGC is small, the signal sensing circuit 114 will switch the amplifier 113 to a higher gain, most preferably 24 dB and when signal is large, the circuit 113 will switch amplifier to a lower gain, most preferably 12 dB gain. The signal sensing is designed to have 6~10 dB hysteresis to prevent frequent switching. The small signal threshold should be higher than the maximum sensitivity of the receiving system (i.e. that at which the signal level hits the signal to noise ratio to achieve the desired bit error rate) and the low gain value (12dB) should be such that the maximum output of the ADC is less than the ADC input range. For example, if at maximum sensitivity, input to the AGC is 5 mVpp and at large signal, input to AGC is limited to 158 mVpp due to the limiter, then the low signal sensing point could be set at about 12 mVpp and high sensing point could be set to 36 mVpp (hysteresis = $20\log(36/12)=9.5$ dB), since 12 mVpp > 5mVpp, the maximum sensitivity level and $36 \text{ mVpp} * 4$ (equivalent to 12 dB gain) < 158 mVpp, the ADC input range limit.

In the first embodiment if the noise figure of the analog components 101-111 is fairly good, it could happen that, before maximum sensitivity is hit, the

5 quantization noise introduced by ADC 112 is larger than the noise generated by analog components. In this case, by improving the analog circuit noise figure will not improve the sensitivity. With the simple switching AGC in Figure 2, this effect of the quantization noise can be minimised. As the amplifier needs to switch between two different gains only, it is easier to design and with the
10 hysteresis, there is minimum switching during communication and hence better BER.

The first embodiment has been implemented in CMOS 0.35um technology and to meet the requirements of the Bluetooth protocol v1.x. With AGC added
15 according to second embodiment, additional 4~5 dB improvement in sensitivity may be achieved. For such implementations, the gain and pole assignments of the components of the described embodiment are as follows:

20	LNA :		Gain = 20 dB
	Mixer :		Gain = 15 dB
	Pole1 : $W_0 = 2\pi \cdot 1.1e6$	$Q = 0.91$	Gain = 6dB @ 1Mhz
25	Pole2 : $W_0 = 2\pi \cdot 0.89e6$	$Q = 0.76$	Gain = 6dB @ 1Mhz
	Pole3 : $W_0 = 2\pi \cdot 0.89e6$	$Q = 1.5$	Gain = 6dB @ 1Mhz

Limiter : Clip voltage : 0.5Vpp

Gain = 0dB

Pole4 : $W_0 = 2\pi \cdot 0.34e6$

Q = 1.4

Gain = -6dB @ 1Mhz

(Low gain to maintain filter linearity)

5

Pole5 : $W_0 = 2\pi \cdot 0.34e6$

Q = 4.5

Gain = -3dB @ 1Mhz

(Low gain to maintain filter linearity)

Amplifier (1st embodiment)

Gain = 12 dB

10

ADC

Sampling Rate: 4Mhz

AGC (2nd embodiment)

Gain = 12/24 dB

The receiving structures described in the first and second embodiments are

15

generally applicable to all FM modulation schemes particularly using

FSK/GFSK, where phase information is not critical.

Claims

1. A signal processing circuit arranged to be used in a frequency modulated signal receiver comprising a complex filter connected to analog to digital
5 conversion means, the filter comprising first and second complex filter stages and a voltage limiter disposed between the stages.
2. A circuit as claimed in claim 1 wherein the first filter stage is arranged to provide gain to a received signal.
3. A circuit as claimed in claim 2 wherein the first stage comprises at least
10 three complex poles.
4. A circuit as claimed in any one of the preceding claims wherein the second filter stage is arranged to filter out higher order harmonics of a received signal.
5. A circuit as claimed in claim 4 wherein the second stage comprises at least
15 two complex poles.
6. A circuit as claimed in any one of the preceding claims further comprising amplifier means disposed between the second filter stage and the analog to digital conversion means.
7. A circuit as claimed in claim 6 wherein the amplifier means comprises an
20 automatic gain control amplifier having a signal level sensor and a controllable amplifier.

8. A circuit as claimed in claim 7 wherein the sensor is arranged to control the gain of the amplifier between two gain levels in dependence upon the level of a received signal.
9. A circuit as claimed in claim 7 or claim 8 wherein the level sensor has
5 hysteresis.
10. A circuit as claimed in any one of the preceding claims wherein the analog to digital conversion means comprises a single analog to digital converter.
11. A circuit as claimed in any one of the preceding claims wherein the output
10 from the second filter stage comprises two signals in phase quadrature, only one of which is input to the analog to digital converter means.
12. A circuit as claimed in any one of the preceding claims wherein circuit elements from the limiter to the analog to digital conversion means are arranged to limit the signal voltage to less than the maximum allowable range of the analog to digital conversion means.
13. A circuit as claimed in any one of the preceding claims further comprising a
15 mixer, connected to the first filter stage.
14. A circuit as claimed in claim 13 wherein the mixer is connected to the first filter stage via DC decoupling means.
15. A circuit as claimed in any one of the preceding claims wherein the circuit is
20 arranged to be used in a Bluetooth receiver.
16. A fm receiver incorporating a circuit as claimed in any one of the preceding claims.

Abstract

A Receiver And A Signal Processing Circuit Therefor

- 5 A signal processing circuit arranged to be used in a frequency modulated signal receiver is disclosed which includes a complex filter 105-110 connected to analog to digital converter 112, the filter having first 105-108 and second 109,110 complex filter stages and a voltage limiter 108 disposed between the stages. The circuit is of particular applicability for use in a Bluetooth receiver.

10

Fig. 1

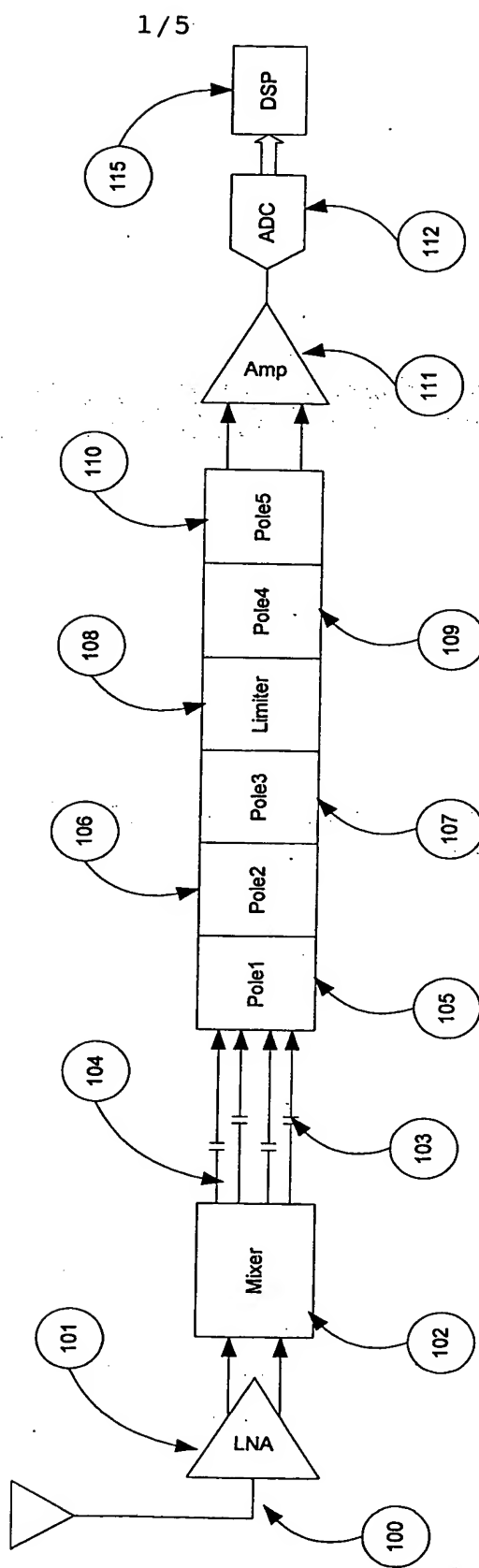


Figure 1

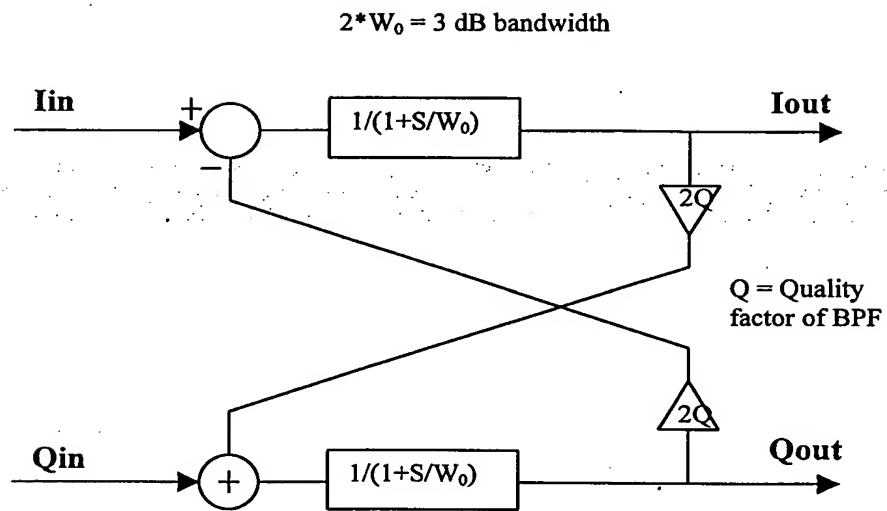


Figure 2

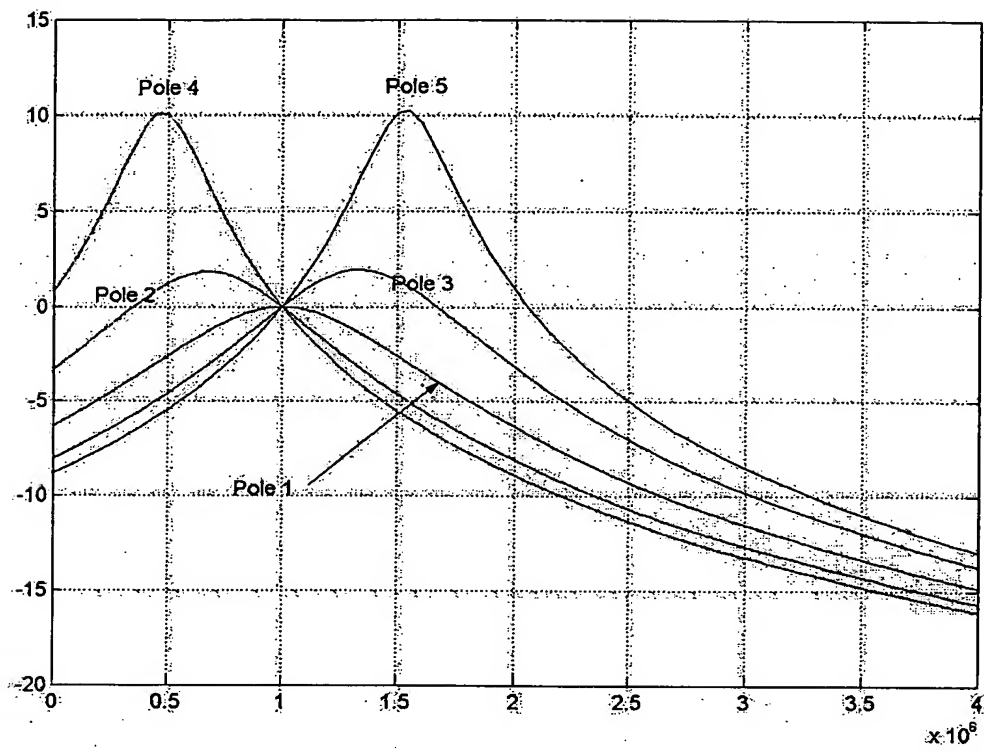


Figure 3

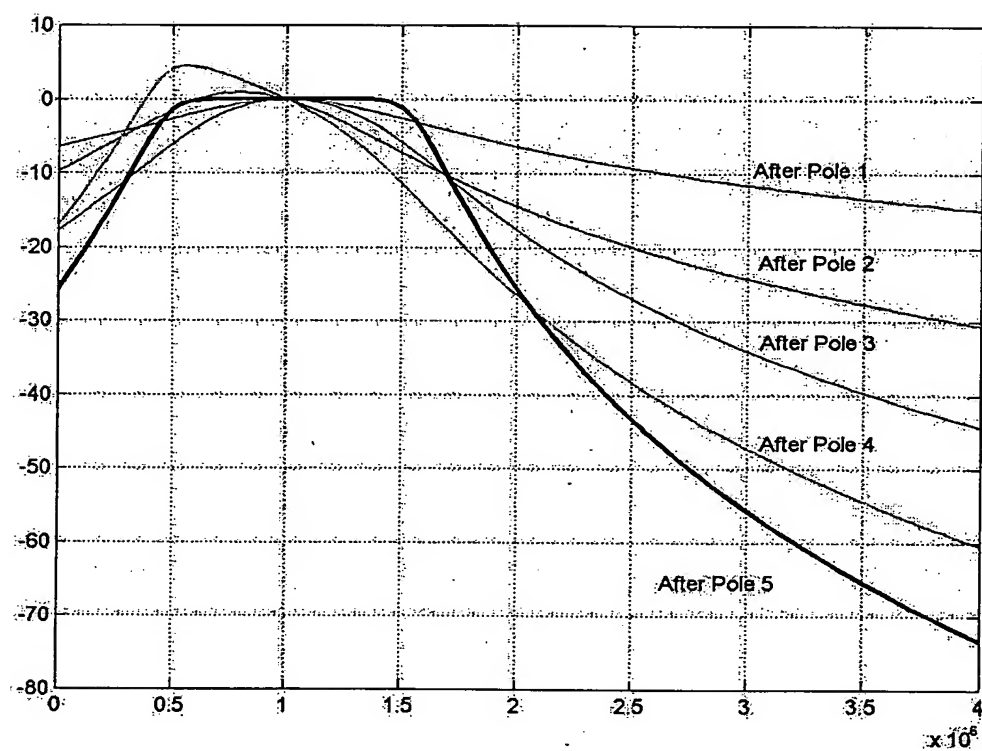


Figure 4

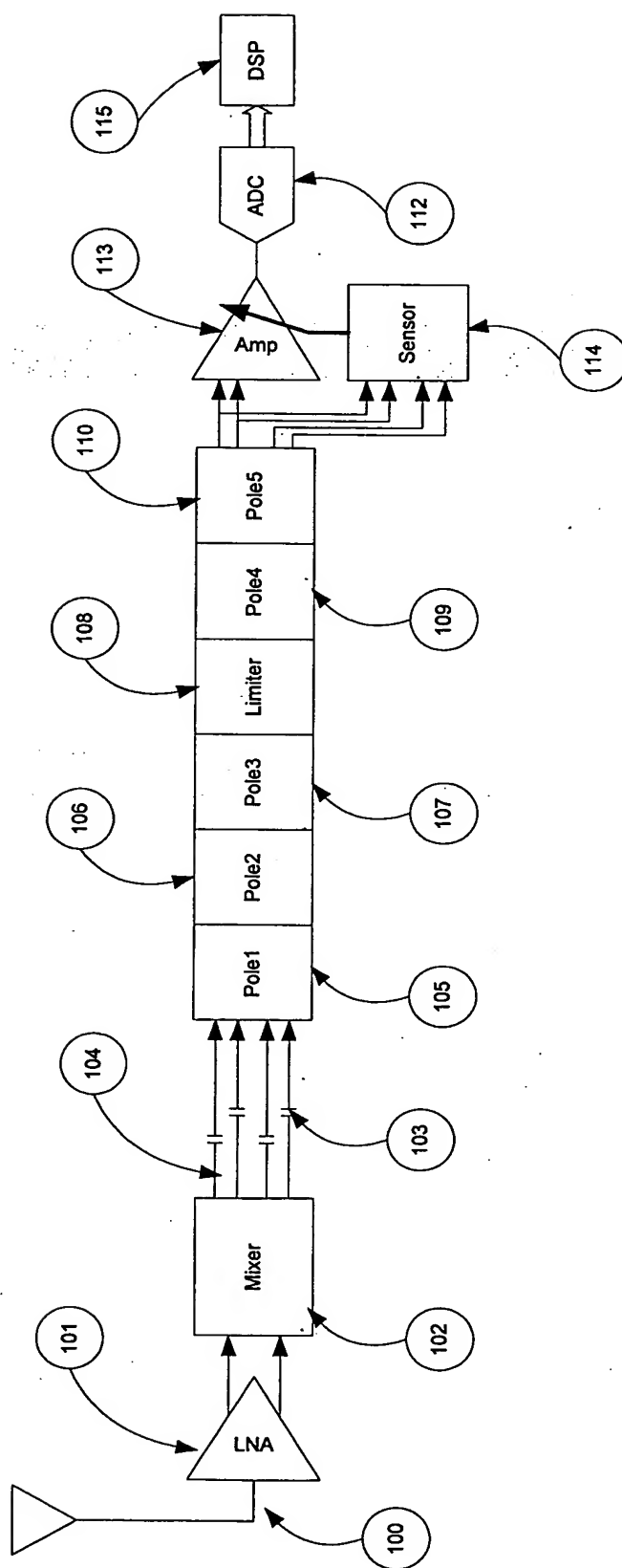


Figure 5